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The Mid-term Forecast Method of Solar Radiation Index† ⋆

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Abstract In the orbital determination of low earth orbit satellites, the solar radiation index $F_{10.7}$ is an important input parameter, which is commonly used to describe the effects on the density of upper atmosphere and orbit perturbation, directly or indirectly caused by solar activities, respectively. So the accuracy of the index $F_{10.7}$ will affect the precision of orbit prediction. Based on the characteristic of the 27-day short-term oscillation in the solar activity, a method is studied in this paper for the 54-day mid-term forecast of $F_{10.7}$ by using its historical data of the past 135 days. Thus the method can predict the variation of solar radiation for the future two rotational periods. In comparison with the other widely-used forecast methods, it is shown that: (1) the method is obviously better than the traditional triangle function method; (2) in the short-term forecast (7 days), the method is a little better than that developed by the Space Weather Prediction Center in USA, and the root mean square could be reduced by about 19%; and (3) in the mid-term forecast (27 days), the accuracy of the method is almost equivalent to the 54-order autoregression method which is used widely in our country, but this method requires to input fewer parameters and historical data, and with a stable precision, it is more convenient in the application of orbit determination. Moreover, up to the 54th day the correlation coefficient between the prediction and the actual index is still greater than 0.92, implying that the method can keep stable in the mid-term forecast. Overall, the advantage of this method is that with fewer historical data of radiation indices, it can make the mid-term prediction of solar radiation as long as 54 days without

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the need of extra solar observation data, to provide the reasonable and reliable solar radiation indices for the short- and mid-term orbit predictions in space flight missions.

Key words sun: radio radiation—celestial mechanics—methods: numerical

1. INTRODUCTION

It is well known that the model of upper atmosphere is commonly used to calculate the atmospheric density in the orbit prediction of low earth orbit satellites. An important input parameter in the mainstream atmospheric models is the index of solar radio flux $F_{10.7}$ at 10.7 cm wavelength (2800 MHz). Started from the earliest model of Jacchia 65, it is always used to construct the equation of temperature in the outer atmosphere, and to describe the heating effect of solar radiations in the upper atmosphere, and some good results have been obtained. There are mainly two reasons for that, one is the remarkable linear correlation between the variation of atmospheric density and $F_{10.7}^{[1]}$ as indicated by statistics, which is helpful to the modeling, and the second one is the ground-based daily observation of $F_{10.7}$ with a mature technology. Since the first observation started in 1947 February[2], the observation has never been interrupted, and therefore has a very long span of time. Of course, some new solar indices have been introduced into the modeling study of upper atmosphere, such as $E_{10.7}$, S_{10}, M_{g10}, and Y_{10} etc[3]. We have systematically studied the positive effects of these indices for improving the modeling precision, meanwhile it is pointed out that their measurements strongly depend on space satellites, and it is not so convenient as $F_{10.7}$ for the data collection and release, thus to cause their limited usage in the orbital determination[4].

The $F_{10.7}$ index is daily observed towards the Sun by the radio observatory of Peng Daike City of British Columbia in Canada, and expressed in units of sfu (solar radiation flux density, 1 sfu $= 1 \times 10^{-22}$ W $\cdot$ m^{-2} $\cdot$ Hz^{-1}). The data file can be downloaded from the websites of the National Oceanic and Atmospheric Administration of USA, etc. (ftp://ftp.ngdc.noaa.gov, www.celestrak.com).

In the orbital determination of spacecrafts, the measured data of $F_{10.7}$ may be directly called in the case of post data processing. However, in the case of orbit prediction, especially, for carrying out a space mission with distinct real-time characteristics (such as the collision warning before launching, the mid- and short-term cataloging forecast and precise prediction, as well as the fall prediction), it is necessary to input the solar radiation indices in the future times from 1∼3 days to several months. But the solar activity in the future time is absolutely unmeasurable, and it is possible only to predict $F_{10.7}$. In this way, the prediction error will be introduced into the atmospheric model, to cause the error in the orbital determination. Hence, the prediction of solar radiation index has a vary large influence on the accuracy of orbit prediction. This paper will focus on the study of mid-term prediction method by using the historical data of $F_{10.7}$ (in two solar rotational periods, 54 days), to satisfy the